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INVESTIGATION OF ELECTRON IMPACT PROCESSES RELEVANT TO VISIBLE LASERS

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Semi–Annual Report for Periods 1 March 1976 to 31 August 1976

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6. Glow Discharge Source
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During this contract period construction of the electron spectrometer has been completed. The performance of the instrument has been appraised from measurements of energy loss spectra in argon and helium. Currently efforts are in progress to reduce the background signal in the instrument arising from the incident electron beam suffering inelastic collisions with various surfaces and eventually scattering into the analyzer optics.

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I. INTRODUCTION

This program addresses one of the major uncertainties in electron excited visible atomic lasers: namely, the significance of electron de-excitation (quenching) of the upper laser level, as well as the magnitudes of the excitation cross sections of the upper and lower laser levels. The process of quenching by electron impact has been identified as one of the critical unknowns of the "forbidden transition laser" concept. It may also be a limitation to the efficiency of the copper discharge laser and of other potential metal atom systems. There is virtually no data in the literature on the low-energy de-excitation kinetics of the relevant atoms, and previous excitation cross-section measurements are in the energy range above 20 eV. A knowledge of these processes is essential for modeling and optimization of laser performance.

The overall objective of this program is to provide the necessary information on the electron kinetics from a combined experimental and theoretical effort, with particular application to copper and lead. Both of these elements have already been used to demonstrate lasing action at several visible wavelengths.[(1)] At present, the only experimental data available for these systems is that of Williams and Trajmar,[(2, 3)] who have measured a limited number of cross section in Cu and Pb, but only for direct excitation from the ground state, and for one or two energies in the range $\gtrsim$ 20 eV.

(1) G. G. Petrash, Soviet Physics Uspekhi 14, 757 (1972).
(2) W. Williams and S. Trajmar, Phys. Rev. Letters 33, 187 (1974).
(3) W. Williams and S. Trajmar, J. Phys. B. 8, L50 (1975).

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On the theoretical side, no previous calculations exist for forbidden transitions in heavy, complex metal atoms. It is therefore the purpose of the proposed program to obtain the required electron impact cross sections and to develop a computational method which will facilitate the search for promising new visible lasers.

It should be pointed out that the emphasis of the present program is to obtain absolute cross sections for the laser systems of interest. For the metal vapors with which we are dealing it is not possible to make accurate absolute measurements, and thus the data will yield relative cross sections which must be normalized. A commonly used method for normalization is to extrapolate the data to extrapolate the data to zero momentum transfer, where the generalized oscillator strength becomes equal to the known optical oscillator strength. This method, however, is highly unreliable and can easily be in error by over an order of magnitude. In the present program, the data will be normalized to the theoretical calculations in the intermediate energy range (above the ionization limit) where strong-coupling effects and resonance phenomena should be minimal, and where the theory should thus be the most accurate. Once the normalization factor is determined, it can be applied to the data over the entire energy range, including very low energies near the excitation threshold where the theory is less reliable.

The combined experimental and theoretical effort will therefore be able to provide the required absolute cross sections with the level of accuracy needed for laser modeling.

The experimental measurements of the relevant cross sections will be performed by observing those electrons inelastically scattered by

electron-atom collisions occurring within a collision volume defined by the interaction of an atomic and an electron beam.

During this period of performance a hemispherical electron-energy analyzer and electron gun (referred to as the electron spectrometer) has been assembled together with the associated electrical control circuitry and has been integrated into the vacuum system.

The performance of this system has been examined and verified by observing energy loss spectra obtained as a consequence of electron collisions with an atomic beam of ground state argon atoms.

II. EXPERIMENT

A schematic of the experimental concept is shown in Figure 1.

The previous Semiannual Report covering the period 1 Sept. 1975 to 29 Feb. 1976 contained an overall description of the design and fabrication of the vacuum system and electron spectrometer.

In this Semiannual Report detailed descriptions of the electron optical components are presented.

Also during this period of performance the electron spectrometer has been assembled and integrated with the vacuum system and control circuitry. An atomic beam source has been incorporated into the system in order to verify the performance of the spectrometer by observing collisons between the electron beam and ground state rare gas atoms.

A photograph of the stainless steel bakeable vacuum chamber and associated pumping system is shown in Figure 2.

The electron multiplier has been integrated into the system and the necessary pulse preamplifier circuitry and high voltage divider network designed and constructed. The operating characteristics of the channeltron have been determined in order to establish the correct mode of operation.

The assembled system is shown in Figures 3 and 4. The hemispherical analyzer is visible on the left and the rotatable electron gun on the right. The atomic beam source enters through the differentially-pumped compartment above these two components.

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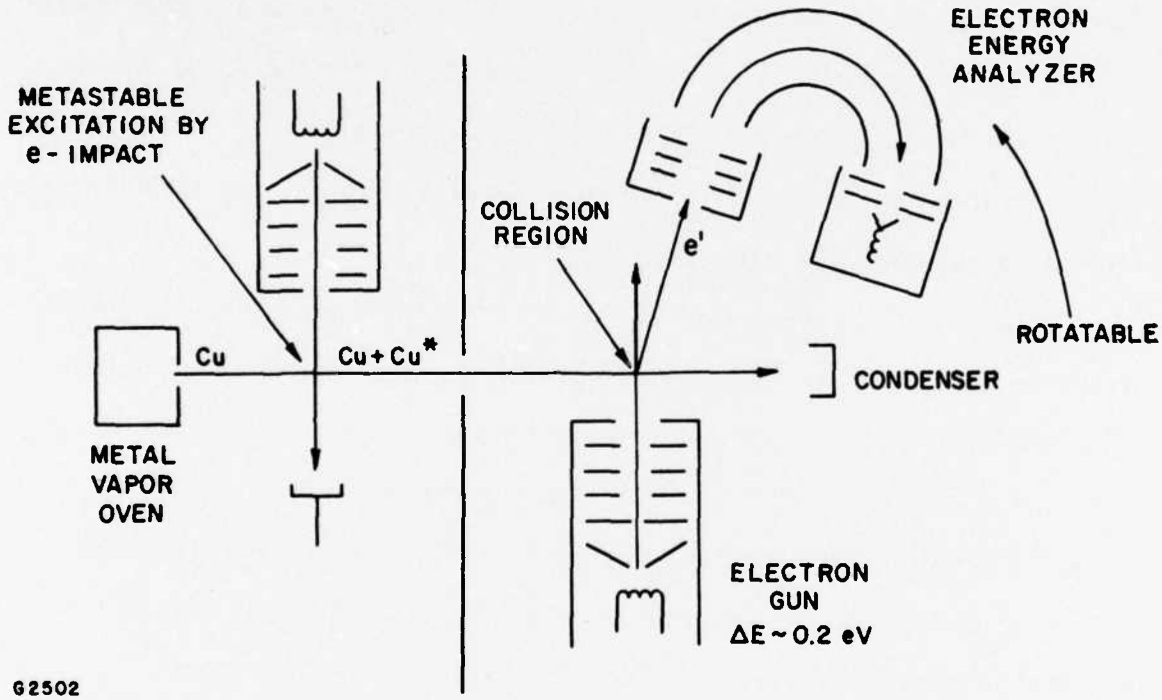

Figure 1 Schematic of Crossed-Beam Apparatus and E-Beam Metastable Excitation Source

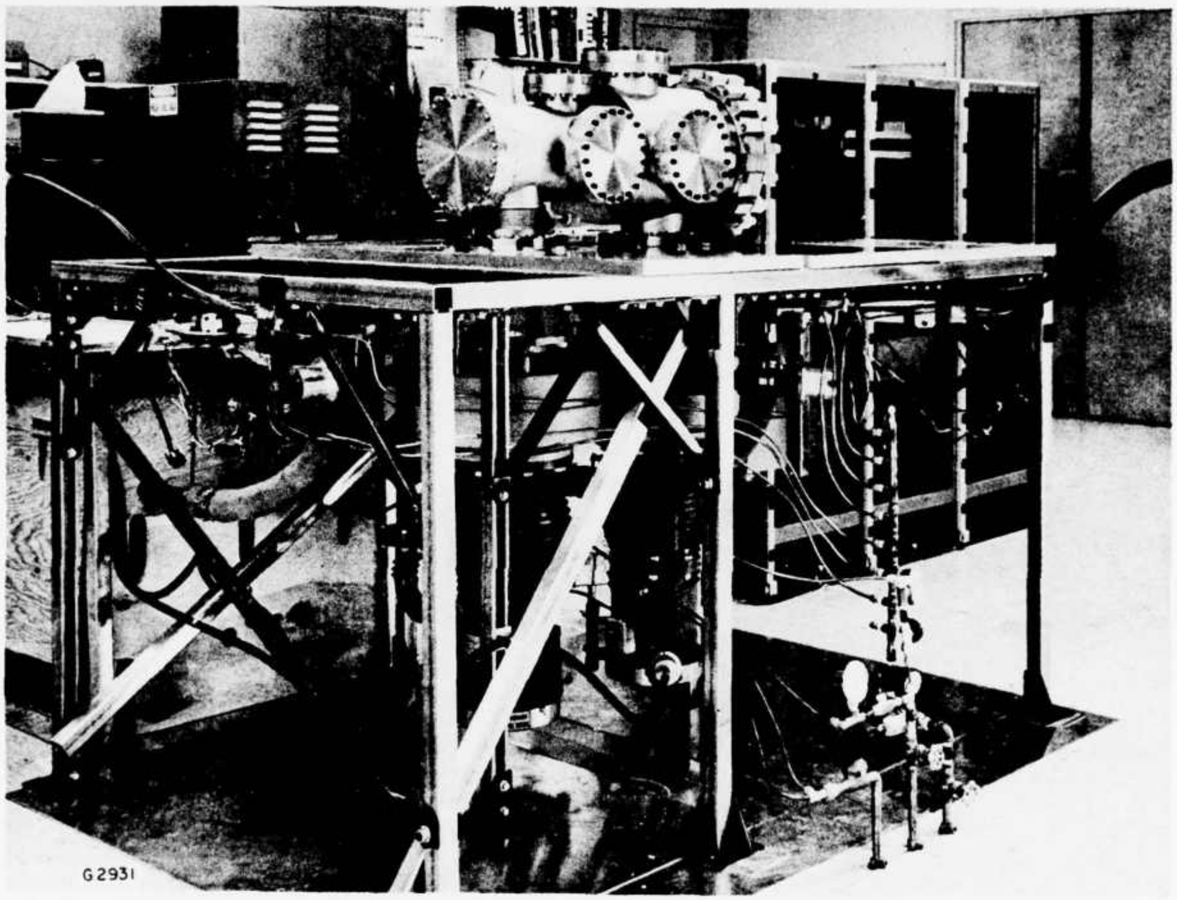

Figure 2 Photograph of the Pumping System and Vacuum System Chamber

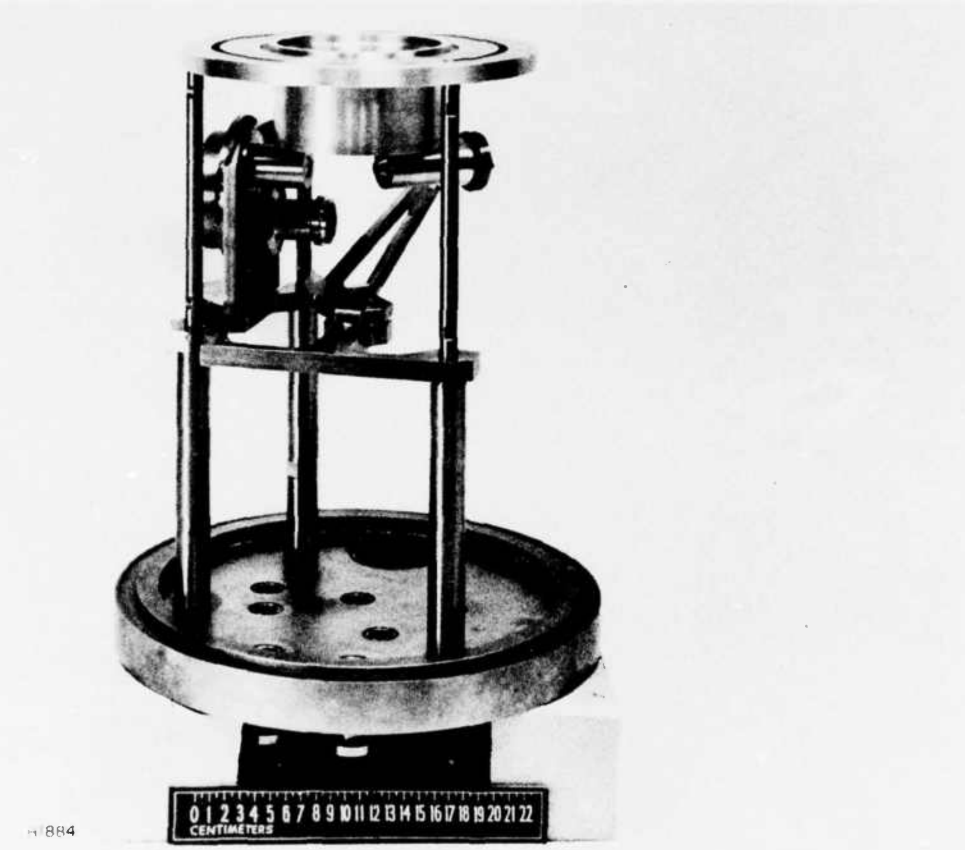

Figure 3 Photograph of the E-Gun and Hemispherical Electrostatic Analyzer

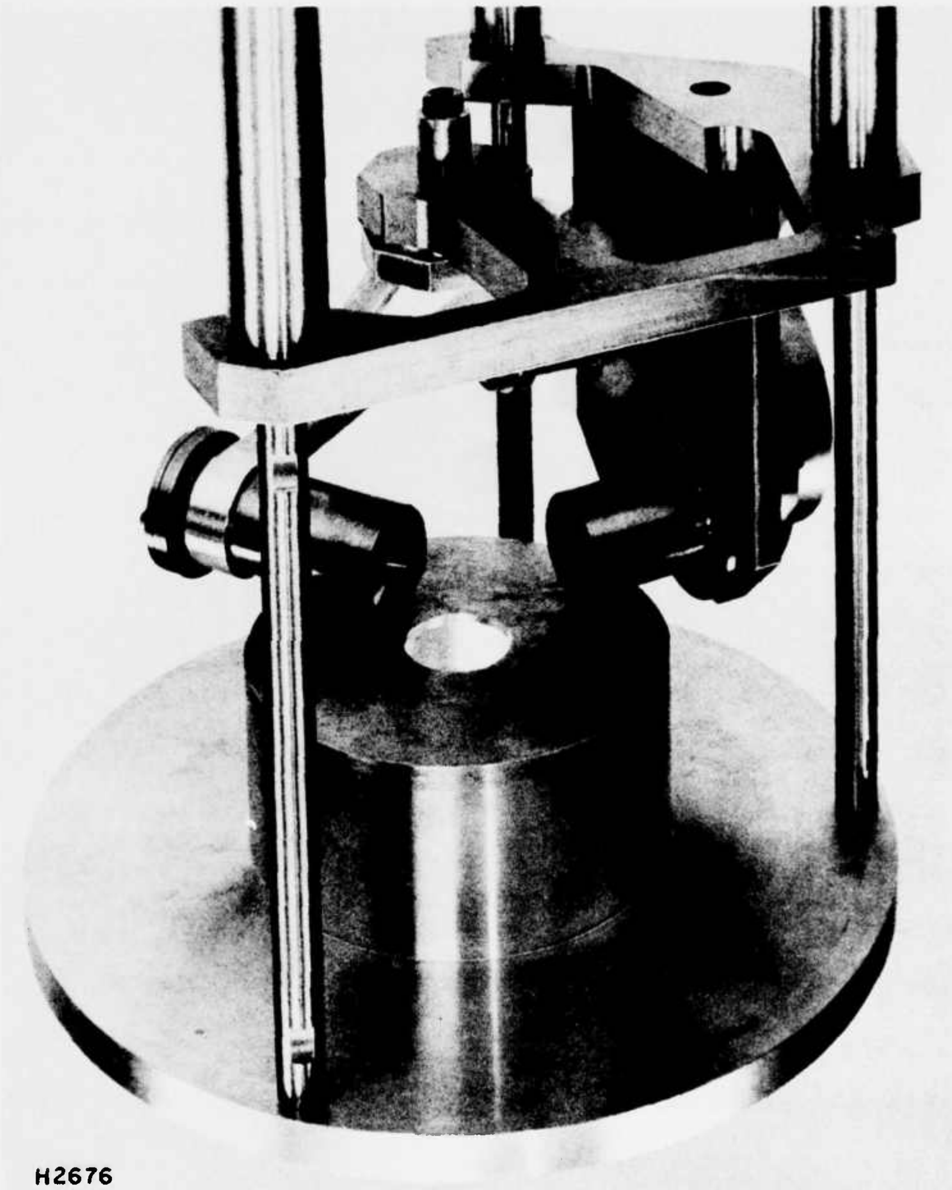

Figure 4 Photograph of the Electron Spectrometer Showing Entrance Aperture for Molecular Beam

A. ELECTRON OPTICAL DESIGN

As previously explained the emphasis of the experimental aspect of the program is placed upon providing relative cross section measurements over the range from threshold to approximately 20 eV. It is essential therefore that over this energy range the transmission and focussing properties of the electron spectrometer be independent of energy in order to ensure constant relative accuracy of the measurement. Thus considerable effort has been directed towards careful design of all the electron optical components of the system in order to obtain the desired energy independent characteristics. Central to this issue is the electron optical design of the electron gun and the analyzer entrance optics shown in Figure 1.

The electron gun should produce a well defined beam of constant angular characteristics and spot size which is focussed onto the atomic beam in the collision volume. The purpose of the analyzer acceptance optics is to subtend a fixed solid angle from the collision region and to transport and focus the electrons scattered into this solid angle in an energy independent manner to the input plane of the electron analyzer.

The key elements which determine these transmission characteristics are the electron optical lenses. In order to produce these energy independent properties considerable attention must be paid to the design of these lenses analogous to the elimination of chromatic aberration encountered in optical lens components.

An example of this design technique is shown in Figure 5 which shows the analyzer entrance optics and part of the hemispherical analyzer in detail. The location of these components with respect to the complete

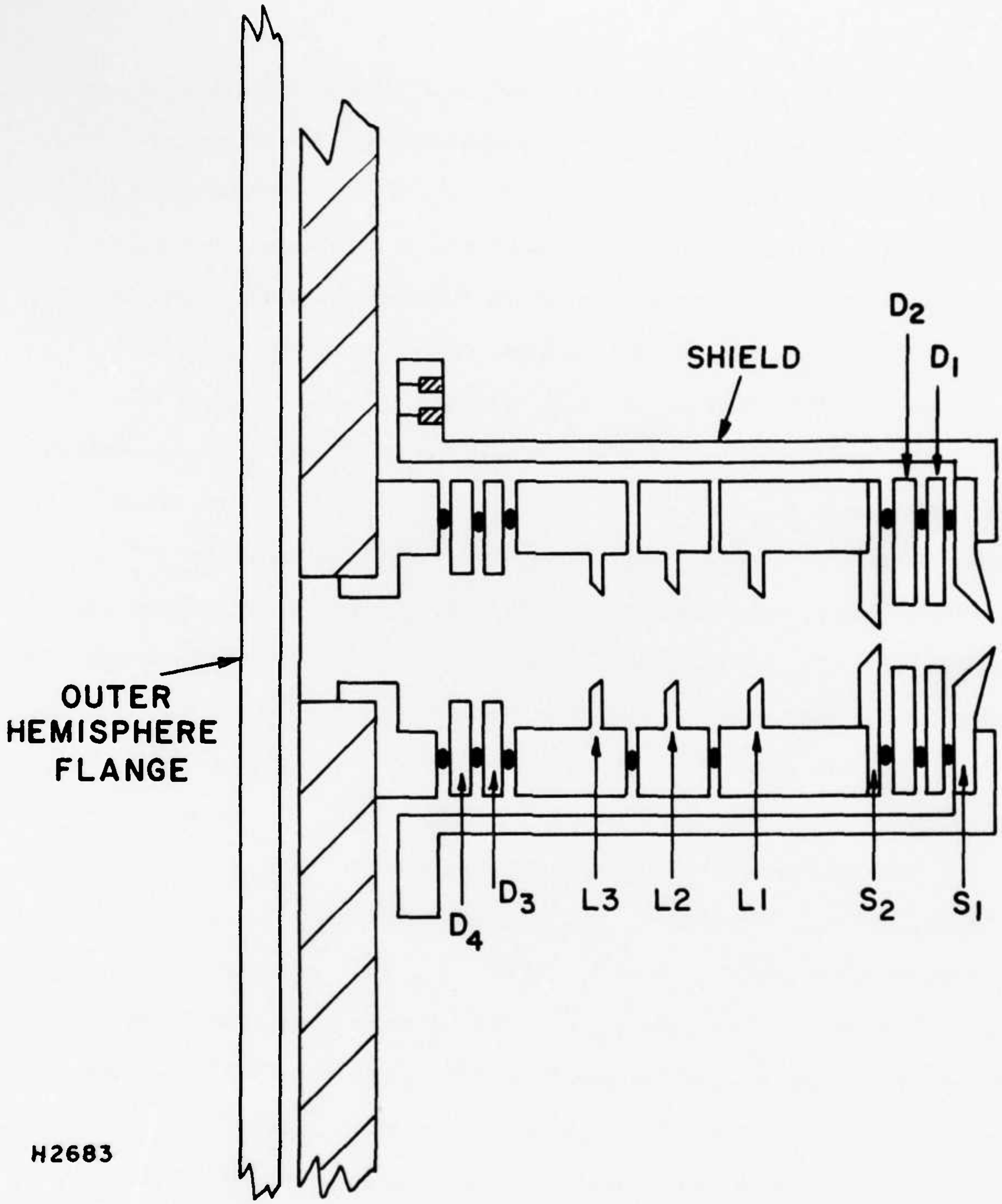

Figure 5 Schematic of the Analyzer Entrance Optics

apparatus can be understood by reference to Figure 1, the schematic of the apparatus. S_1 and S_2 are angular stops which define the acceptance angle of the electron optical system D_1, D_2 and D_3, D_4 are perpendicular pairs of electric deflecting plates whose purpose is to compensate for minor perturbations of the electron beam due to residual magnetic or electric fields. The heart of the electron optical system is the three-element aperture lens defined by the circular apertures L_1, L_2, and L_3. The properties and characteristics of this lens are as follows. The purpose of the lens is to focus an image of the collision region onto the entrance plane of the electron analyzer. The design adopted is due to Read[(4)] and is referred to as a three element zoom lens, again by analogy to the optical counterpart. The characteristic property of the zoom lens is to produce an image of constant magnification and location which is independent electron energy, of course the optical zoom lens possesses variable magnification, the point in common between the two being the fixed image location.

The lens is operated in the following manner. Element L_1 is maintained at constant potential V_1 which should be the same as the potentials applied to S_2, S_1 and the collision region, this ensures constant acceptance angle characteristics for the system. The potential of the region to the left of and including L_3 is maintained at a constant value V_3 commensurate with the required operating energy of the electrostatic analyzer and again to achieve constant transport properties beyond L_3. The potential applied to L_2 namely V_2 is variable and varied according to the electron energy in order to maintain fixed focus at the entrance of the electrostatic analyzer. The relationship between V_1, V_2 and V_3 has been computed by Read using

(4) Read, F. H. J. Phys. E. 3 127 (1970).

computer generated trajectory calculations for the electrons by calculating the potential distribution within the lens system from numerical solutions to Poissons equation. Examples of the relationship between these potentials is shown in Figure 6. The different curves correspond to different values of the P, Q or object and image distances of the system. The numerical values of P and Q are ratios of the conjugate distance to the lens aperture diameter.

In practice in order to obtain a spectrum of scattered electron energies, V_1 is held constant and V_3 is driven by a ramp voltage. The ramp voltage is applied to the input of a voltage programming circuit in order to produce the proper response voltage V_2 which is applied to lens element L_2. A similar procedure is adopted when operating the similar zoom lens contained within the electron gun.

A photograph of the electron gun with the shield removed and showing various electron optical elements is shown in Figure 7. The lighter shade split plates are the beam steering plates. The elements are aligned and insulated from each other by 1/16 dia sapphire balls mounted in accurately machined recesses. All component parts are fabricated from molybdenum. The electron source is a directly heated thoria coated iridium filament.

B. CHANNELTRON CHARACTERISTICS

The channeltron multiplier purchased for the experiment was a Bendix (Galileo Enterprises) model CEM4039 three turn helix with a 10 mm entrance aperture. Typical gain at 2800 volts was rated at 1×10^8 and dark count in 0.5 count/rec.

Great care was taken to mount the channeltron in a completely shielded enclosure which clamped tightly to the exit plate of the

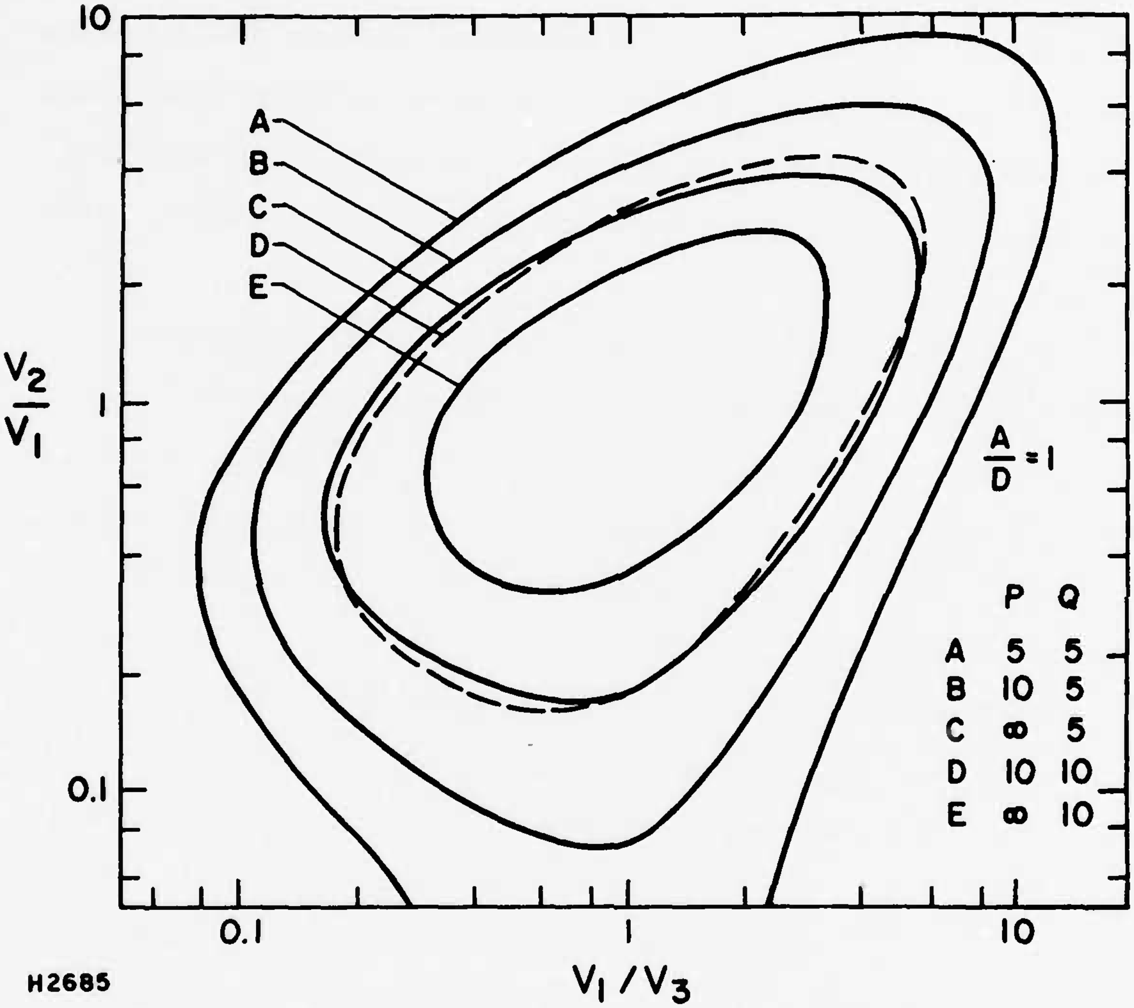

Figure 6 Zoom Lens Characteristics

Figure 7 Photograph of the E-Beam

hemispherical analyzer such that access to the multiplier could only be achieved via the exit aperture of the hemispherical analyzer. This precaution was taken to minimize background signals arising from stray scattered electrons. Details of the multiplier housing are shown in Figure 8. High voltage connections to the multiplier and Faraday collector cup were made via the Ceramaseal feedthroughs which also served as mounting posts for the multiplier and collector. Details of the high voltage divider network and pulse preamplifier circuit are shown in Figure 9. The pulse preamplifier has a voltage gain of x10 and converts the high impedance channeltron output to low impedance and is mounted on the output signal vacuum feedthrough. The pulses are then transmitted to standard Canberra Industries Nuclear pulse counting equipment comprising, amplifier and pulse shaper, high and low level discriminator, counter, ratemeter and finally displayed on an X-Y plotter. For signal averaging purposes the pulses can be fed to a Nicolet multichannel analyzer where repetitive scans of a spectrum may be made and accumulated in the memory of the averager.

The pulse height distribution obtained from the channeltron was measured as a function of various applied high voltage by using a narrow window defined by the single channel analyzer to scan the distribution.

A typical desirable distribution is shown in Figure 10. The large amplitude spike at low pulse height corresponds to noise from various sources and the second maximum true channeltron pulses. By appropriate placement of the single channel analyzer window to accept only pulses contained in the higher pulse height maximum the signal-to-noise ratio determined by external sources of noise can be optimized.

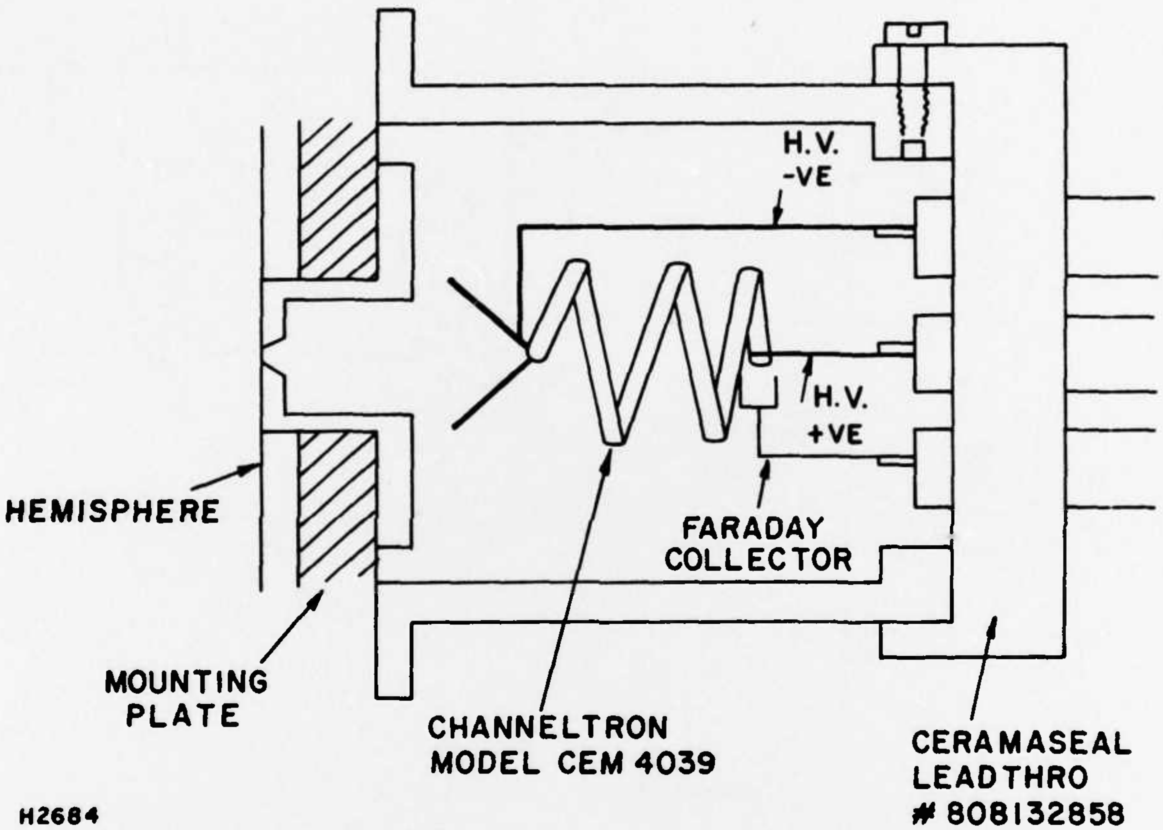

Figure 8 Schematic of the Channeltron Housing

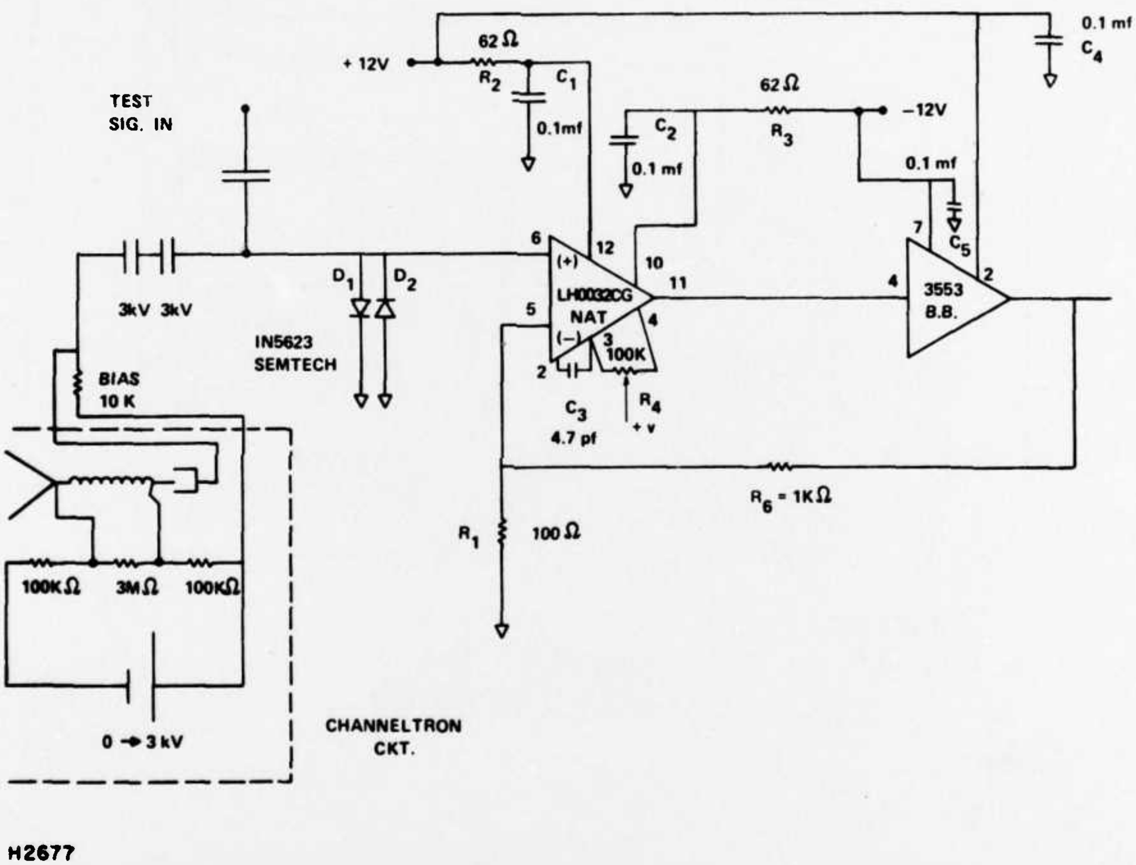

Figure 9 Channeltron High Voltage Divider and Pulse Preamplifier Circuit

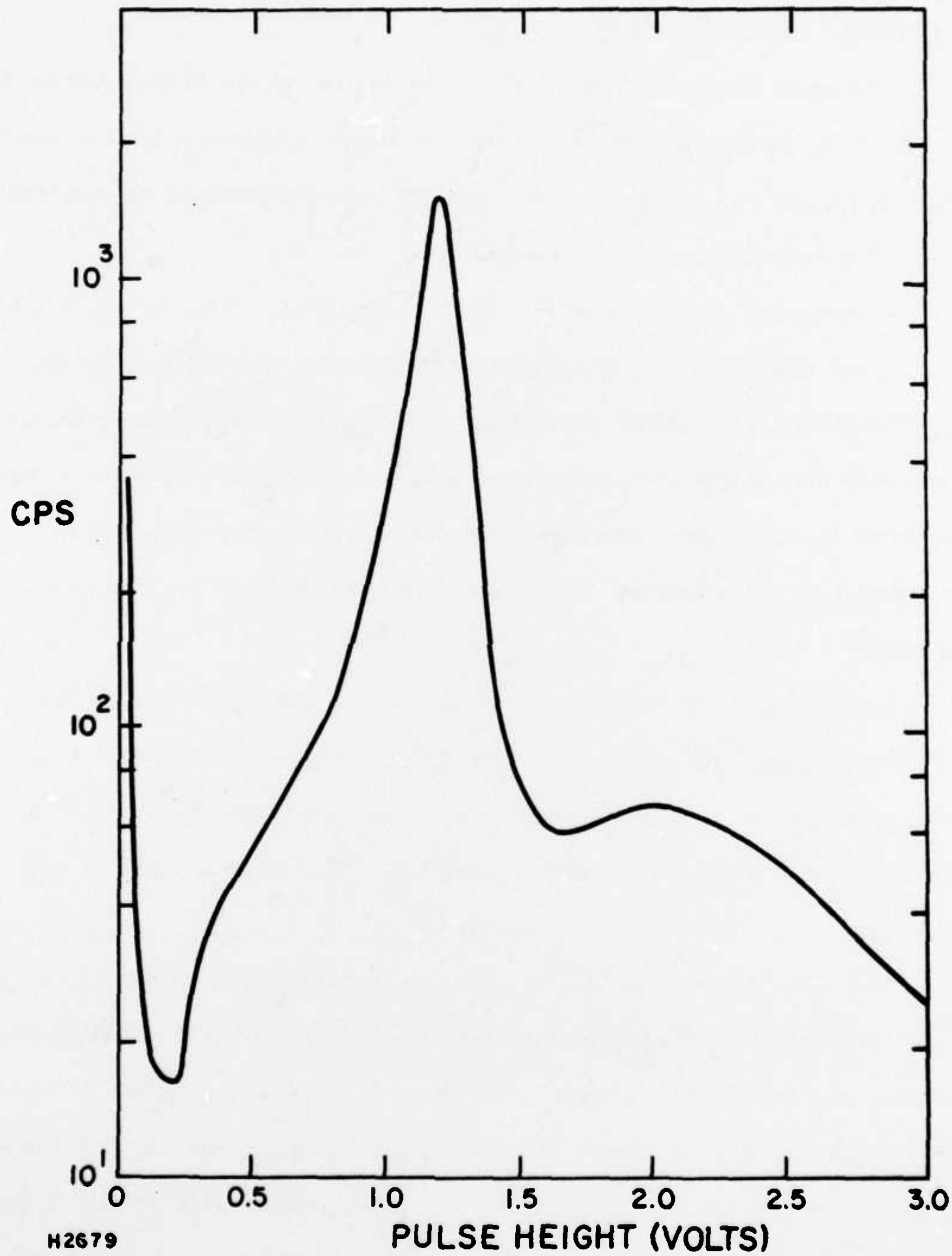

Figure 10 Channeltron Pulse Height Distribution

C. SYSTEM VERIFICATION

The performance of each of the component parts of the system has been carefully verified. The electron gun which employs a thoria-coated iridium filament has been activated and the current-voltage characteristics have been determined over the range 0 - 50 eV.

A potential divider network was designed and constructed in order to supply the necessary voltages to the channeltron multiplier and Faraday cup. The pulse shape characteristics of this device have been measured over a wide range of operating voltages in order to determine the optimum location of the high level and low level discriminator levels so that unwanted noise lying beyond the range of required pulse heights can be eliminated.

The energy distribution of the incident electron beam has been examined with the hemispherical analyzer by directly scanning the beam profile. The energy distribution is consistent with that expected from a directly heated hot filament source namely ~ 0.4 eV full width at half maximum.

In order to examine the performance of the entire integrated system, energy loss spectra were recorded by examining the energy distribution of electrons scattered from a beam of ground state argon atoms. In order to record such spectra the gun is placed at some convenient angle and the incident beam energy maintained at a constant value while the electron monochromator scans the energy distribution of those electrons which are scattered by the argon atom beam into the solid angle defined by the entrance optics of the electron energy analyzer. The pulses from the channeltron multiplier are amplified by a pulse pre-amplifier located on

the signal vacuum feedthrough. This amplifier also converts the high impedance, high voltage channeltron output to low impedance and capacitively decouples the signal from the high voltage. This signal is then taken to a pulse shaping amplifier, to a discrimator and displayed on a ratemeter. The spectrum is recorded by synchronizing the channel address staircase voltage of a Nicolet 1040 signal averager with the energy scansion voltage of the electron energy analyzer. In this way repetitive scans of the spectrum can be recorded and stored in the memory of the signal averager. For the spectrum shown in Figure 11 the signal-to-noise ratio was such that a single sweep was sufficient to clearly reveal the details of the energy loss spectrum. The spectrum shown in Figure 11 is an energy loss spectrum of electrons inelastically scattered from argon at 50^{o} scattering angle and an incident energy of 40 eV. The elastic peak is not shown, only details of the inelastic spectrum are shown. The abscissa corresponds to the energy lost by the incident electron and therefore represents the energy location of the state excited during the collision encounter. The 4s and 4p, first and second excited valence states are clearly observable, the third peak is a superposition of the 3d and 5s states which are indistinguishable owning to the broad distribution of the incident beam. Beyond the 3d, 5s peak the loss peaks cannot be separately resolved and blend into the ionization continuum indicated by the arrow at 15. 8 eV.

The energy loss spectrum shown in Figure 11 can be interpreted with the aid of the energy level diagram shown in Figure 12. The arrows indicate that the 4s J= 1 states are optically connected to the ground state. The high density of substates comprising the 4s and 4p levels is evident and cannot be separately resolved in the energy loss spectrum.

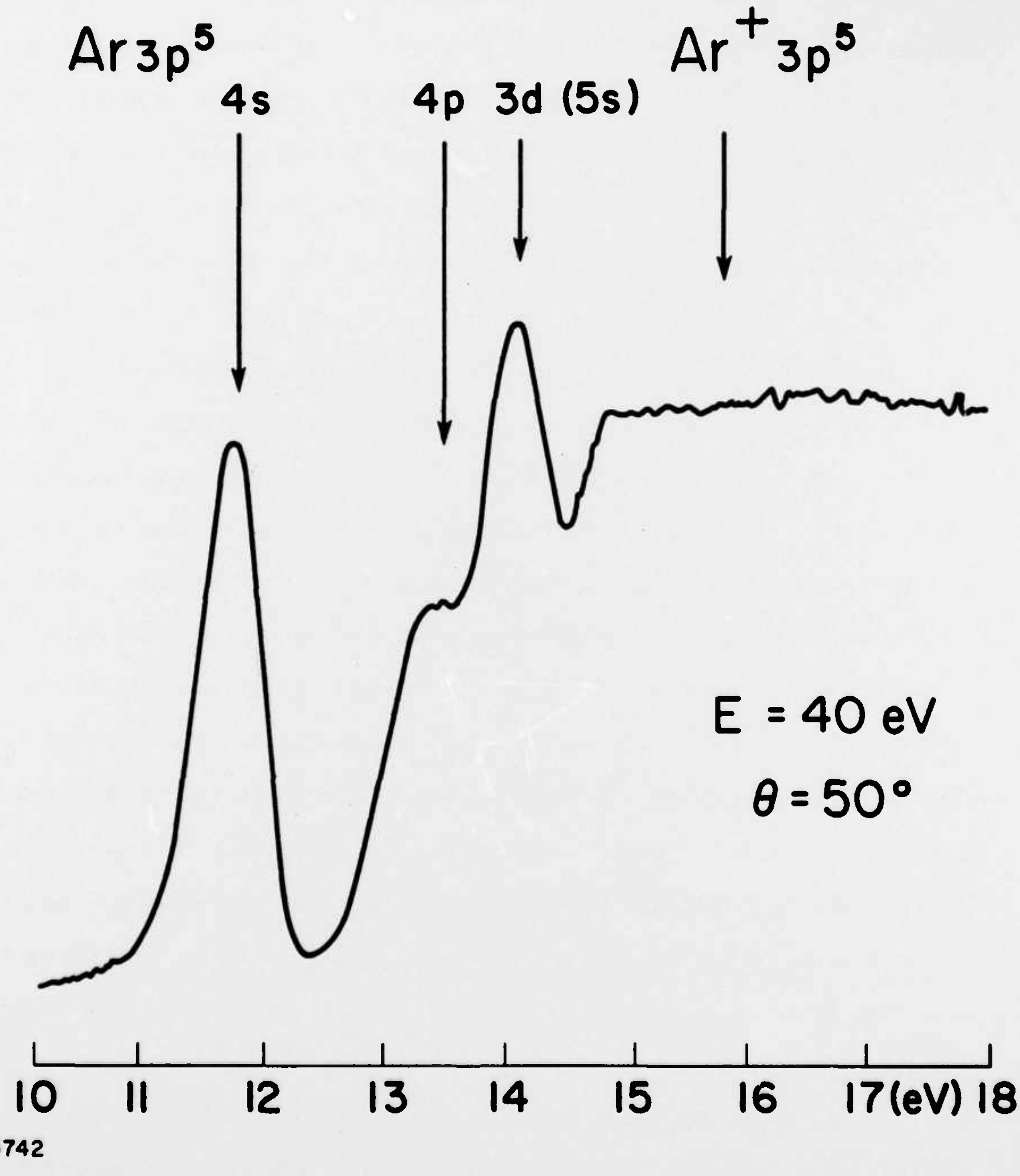

Figure 11 Energy Loss Spectrum for Electron-Argon Scattering Obtained at an Incident Energy of 50 eV and a Scattering Angle of 50°

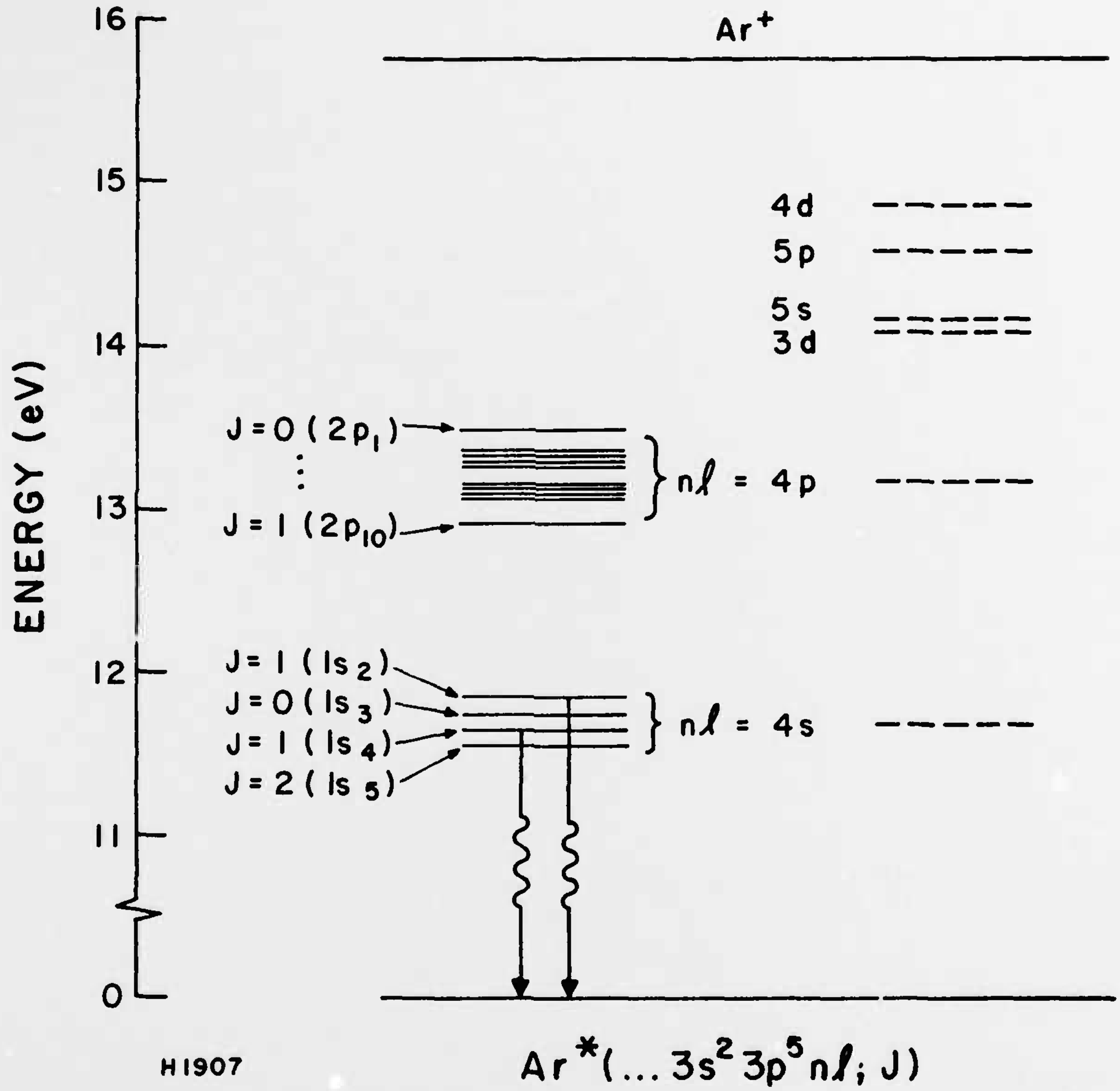

Figure 12 Partial Energy Level Diagram for Argon

III. PRESENT STATUS

Preliminary experiments have been performed and have demonstrated satisfactory performance of the experimental system for the acquisition of energy loss spectra from ground state atomic species.

Since the signals anticipated in the electron-metastable scattering experiment are anticipated to be extremely small the next step is to investigate the signal-to-noise characteristics of the system with a view to minimizing the signal due to background scattered electrons which reach the detector via random collisions with various surfaces. It will be necessary to design and fabricate an efficient beam-dump which should capture the incident electron beam after it has traversed the collision region and before collisions with the instrumental surfaces occur.

Various designs of metastable sources are being reviewed and the final design choice will be made shortly.

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REFERENCES

1. G. G. Petrash, Soviet Physics Uspekhi 14, 757 (1972).
2. W. Williams and S. Trajmar, Phys. Rev. Letters 33, 187 (1974).
3. W. Williams and S. Trajmar, J. Phys. B. 8, L50 (1975).
4. F. H. Read, J. Phys. E. 3, 127 (1970).

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